Control Strategies for Networking Multiple Autonomous Vehicles

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LONG-TERM GOAL

The long term goal is to design, develop, and demonstrate control strategies for the networked control of multiple autonomous vehicles in surf zone mine reconnaissance operation. Specific goals are 1) achieving the mission-required coverage within a specified time-frame, and 2) reporting back mission-critical contacts.

OBJECTIVES

Control strategies for networked control of multiple autonomous vehicles require the investigation and integration of multiple task areas to achieve the full solution. The objectives for this effort consist of the integration of four critical task areas: 1) a distributed control framework for multiple vehicles, 2) a communication protocol between members of the autonomous group and outside agents, 3) map-building capability of objects of interest to report back, and 4) analysis of candidate strategies through simulation.

APPROACH

We are pursuing biologically inspired behavior-based techniques for distributed and robust vehicle control, with three possible modes of operation. The first mode requires developing and implementing component behaviors (e.g., disperse, aggregate, follow, etc.) that would provide the "toolbox" of autonomous tasks for implementing the search schemes. We have already validated this principle of component behaviors in the laboratory setting at the University of Southern California (USC). The second mode uses the component behaviors and interfaces with the human operator to provide semi-autonomous control with significantly increased communication requirements. The third mode assumes autonomous operation with the human operator still in the loop but having relinquished much of the decision points to the autonomous group. The primary framework for these three modes is the development of basis behaviors operating in a behavior-based controller design. This will allow real-time, low overhead processing of controller constructs for each group member with robust group dynamics.

A powerful extension to this behavior-based design is the development of a behavior-based Common Control Language (CCL) for interaction between agents (i.e., swimming, bottom crawling and human operator) during group operations.

Finally, cognitive map-directed search and map building effort is summarized in the end-of-year report submitted by the third member of this team, Nestor Schmajuk from Duke University.

WORK COMPLETED

We have made progress in the following areas: 1) distributed multi-vehicle control in the context of two tasks: resource transport and multiple-target tracking; 2) development of a common vehicle programming language (CCL), and 3) hardware design for High Level Controller

USC has developed and experimentally validated the Broadcast of Local Eligibility (BLE) technique for principled, scalable, robust coordination of groups of mobile robots. This technique facilitates rapid bottom-up design and development, extensive code re-use, and transparent integration of heterogeneous systems. It is based on the exploitation of "situatedness", which is exemplified by ants and other natural systems. The USC team has extended previous experiments with insect-like, physically situated systems to systems situated in abstract "behavior space." NUWC and USC have defined scenarios for groups of two or three swimming vehicles performing a wide-area search and using the BLE technique to address real-time re-assignment of group tasks when initiated by a human operator.

We have also introduced the concept of the behavior-based Common Control Language (CCL) which provides the technology for inter-robot and operator-robot communication. Since behavior-based controllers can be built at run-time, due to the dynamic nature of module connections themselves, a natural "command language" is implied by the Port Arbitrated Behavior (PAB) approach – one in which only four simple behavior-manipulation commands (instantiate, connect, send, request-value) allow systems to be constructed on the fly, monitored, and controlled. The Port Arbitrated Behavior Control Language (PABCL) depends on the existence of a set of appropriate basis behaviors (similar to basic electronic components such as logic gates or amplifiers), on each of the autonomous vehicles. Given those, most complex behaviors can be constructed. For convenience, though, a set of more powerful basis behaviors tailored to the task domain are preferable. Significant progress has been made towards a full implementation of PABCL.

USC has applied the behavior-based framework to demonstrate a team of real robots that cooperate to robustly transport resource between two locations in an unknown environment. The robots use a trail-laying and following algorithm inspired by trail following of ants and the waggle dance of honeybees. Rather than directly marking their environment, the robots announce landmarks in their odometric localization space. The system tolerates significant odometric drift. We also designed and implemented a suitable behavior-based signaling system independent of the navigation strategy employed. We demonstrated it on top of the trail-forming algorithm described above, and showed that dominance hierarchies are not useful in this class of system. Finally, we discussed ways to increase the efficiency of the system by incorporating the right kind of temporal information into an aggression function.

Buildings on USC's previous work in decentralized behavior design for robot teams, and have shown how a biologically inspired aggressive signaling strategy reduces interference in a realistic multi-robot resource transport task. USC showed that previously described anti-interference measures are not appropriate for this class of task; they designed and implemented a suitable behavior-based signaling system independent of the navigation strategy employed. We demonstrated it on top of the trail-forming algorithm described above, and showed that dominance hierarchies are not useful in this class of system. Finally, we discussed ways to increase the efficiency of the system by incorporating the right kind of temporal information into an aggression function.

Last year, USC reported on the development of Multiple Objective Behavior Coordination (MOBC), an approach to finding pareto-optimal solutions, i.e., those that formally address the trade-off between a set of task/system constraints and mission objectives. This year, in the domain of multi-target tracking, we extended MOBC to robot groups, and demonstrated robust target surrounding and tracking.

The proposed integration of behavior-based control with the vehicle controller of a candidate autonomous platform has been addressed by defining the concepts of Low Level Controller and High Level Controller. The Low Level Controller refers to the current vehicle controller of the platform (whether bottom crawling or swimming) that interfaces with motor actuators and sensors. The High Level Controller refers to the controller both hardware and software that we are developing to perform behavior-based control for group operations. NUWC is defining the hardware configuration for the interface of the High Level Controller with the Low Level Controller. We have obtained PC104 Pentium/486 processor boards as the configuration for the High Level Controller. We are looking at LINUX (small kernel) operating system with AYLLU behaviors running on top of that. AYLLU is a commercial available tool developed by Barry Werger (USC) for development of distributed control systems for groups of mobile robots. We are currently using AYLLU for behavior development for the bottom crawlers. RS232 Serial interface would provide data exchange between High Level Controller and Low Level Controller.

We have addressed the proposed integration of behavior-based control with the vehicle controller of a candidate autonomous platform by defining the concepts of Low Level Controller and High Level Controller for the platform. The Low Level Controller refers to the current, existing vehicle controller of the platform (whether bottom-crawling or swimming) that interfaces directly with sensors and motors. The High Level Controller refers to both the hardware and software of the behavior-based control we are developing for group operations. NUWC is defining the hardware configuration for the interface between the High Level and Low Level Controllers. The RS232 serial interface is planned for providing communication between the two controllers. We have obtained the PC104 Pentium/486 processor boards as the configuration for the High Level Controller. We are exploring the LINUX (small kernel) operating system with AYLLU behaviors running on top. AYLLU is a commercially-available tool developed by Barry Werger (USC) for designing of distributed control systems for groups of mobile robots. We are currently using AYLLU for behavior development for the bottom crawlers.

RESULTS

We have made contributions in the following areas: 1) BLE-based control, 2) demonstrations of tracking and resource transport, 3) a PAB based Common Control Language approach, and 4) preliminary High Level Controller hardware component design and interface specification to the Low Level Controller

Significant advancements have been made in the area of adaptive task assignment within a group using the Broadcast of Eligibility. USC demonstrated that the port-arbitrated behavior-based control paradigm could be extended in such a way that robust, scalable fully distributed control for robot teams can be designed and implemented in a principled manner. A standardized, general technique such as BLE is a major step towards analyzable behavior-based systems. Further, PAB interaction, and BLE in particular, are principled means of gaining many of the advantages of biologically inspired, situated systems. Previous insect-inspired multi-robot systems were able to take advantage of the fact that they were situated in the physical world to gain robustness and scalability while minimizing requirements for local (individual-robot) complexity, but these systems were constructed in a fairly ad-hoc manner. Our research has shown that PAB systems can be seen as situated in an abstract “behavior space,” and that BLE is able to structure this behavior space in a principled manner. BLE systems are as a result responsive to both their physical and behavior-space environments, gaining the benefits of situatedness while being quick and straightforward to design and implement.

The work on cooperative resource transport showed how a biologically inspired aggressive signaling strategy reduces interference in the same realistic multi-robot resource transport task. Previously described anti-interference measures were shown to not be appropriate for this class of task; we designed and implemented a suitable behavior-based signaling system, and demonstrated it on the same task. Furthermore, we showed that dominance hierarchies are not useful in this class of system.

In the task area of Common Control Language development, this year's efforts have resulted in the introduction of a PABCL mechanism for extending behavior-based design into a language definition that provides compact data-driven communication scheme. PABCL lead naturally to a change in the concept of a “control language” used to command and interact with multi-robot systems. Rather than a conventional Control Language, which has basic commands related to vehicle capabilities (e.g., MOVE, REPORT), and the associated difficulties of uniform syntax and semantics across robots, our concept of a behavior-based control language has basic commands for behavior manipulation, and standard-interface behavior libraries. The language itself is thus both simplified and more flexible, and allows on-the-fly modification of system behavior in unforeseen ways.

To implement group behavior-based processing, a preliminary High Level Controller hardware component design has been defined based on a PC104 Pentinum/486 processor, LINUX operating system kernel, and AYLLU behavior development tool with an RS232 interface specification between the High and Low Level Controllers. The interface provides compatibility with existing processors on potential application platforms. The LINUX kernel provides a compact operating system with minimal memory requirements for candidate embedded processors.

IMPACT/APPLICATION

The Broadcast Local Eligibility control construct has been applied in the laboratory at USC, in the context of multi-target observation and tracking. This capability would support the operator requesting additional tasks without the need for specific assignment of vehicles to the tasks. For example, an operator can select areas where more search is required, and the group would adaptively assign the task to a member or sub-group.

The PABCL has introduced a mechanism for extending behavior-based design into a data-driven communication scheme for multiple heterogeneous agents. The ability to easily modify individual and group behavior at all levels, indeed to reconstruct controllers on-the-fly through simple, efficient behavior manipulations, speeds up the development process significantly and provides for emergency changes to deployed systems.

TRANSITIONS

AYLLU Behavior Development Tool (developed by B. Werger from USC and commercially available) has been augmented to be "CCL Ready". This means allowing behaviors to be activated/de-activated/modified dynamically through a CCL message from an operator/other platform. A list of Basic Behaviors was distributed to CCL Working Group including a diagram of each behavior with Sensor and Motor Interface requirements. Motor/Actuator Interface is compatible with Low-level Command set developed by Mitch Gavrilash (NSWC-Coastal System Station).

RELATED PROJECTS

NUWC has several in-house swimming UUV programs ranging from single large vehicle operation (e.g., MANTA, 21-UUV) to small vehicle operations (e.g., REMUS) for oceanographic operations.

A new initiative in simulation-based design is investigating the use of "smart" software agents for system design and integration tools for torpedo engineers. The software agents will interact as a part of a "design team" with data exchange and varying levels of decision-making or behaviors. We will be investigating the transition of behavior-based control concepts to this problem area.

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